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# Health monitoring techniques used to thermally characterize satellites

Derek Doyle, Derek Hengeveld, Whitney Reynolds, and Brandon Arritt

*Acoustic waves can be used to effectively measure thermal conductance features at structural interfaces.*

Thermal vacuum (TVac) testing is critical to the verification and validation process for space systems. During this testing, a satellite is submitted to vacuum conditions and extreme temperature cycles, allowing engineers to verify the thermal performance of the full system and to validate thermal models. However, uncertainties involved in the measurements often dominate errors in the system-level models. In addition, accidents occur during satellite assembly, integration, and test (AI&T) and during handing, despite lengthy safety procedures and documentation.[1] Such incidents may be trivial or catastrophic and can result in restoration costs that exceed hundreds of millions of dollars. Much of this cost arises due to delays and duplicate testing.

At the Air Force Research Laboratory Space Vehicles Directorate (AFRL/RV) we have investigated different methods for assessing the structural integrity of complex assembled systems.[2,3] Our recent research[4] has been focused on implementing structural health monitoring (SHM) techniques to provide real-time thermal characterization of system interfaces during TVac testing. This sensing technique (patent pending) is widely applicable to the measurement of conductive heat transfer parameters within a structure and could be used as an alternative to TVac testing. Successful integration of this methodology could provide insight into thermal or structural changes in system performance that may arise before, during, or after the launch of a satellite.

Piezoelectric disks are used in our new approach. The reciprocal electro-mechanical cooling property of the disks allows them to act as both actuators and sensors (up to MHz frequencies) of Lamb waves in our setup. Lamb waves are guided waves that propagate within thin structures. They consist of symmetric and anti-symmetric modes and cause particle motion both in and out of plane displacement. Changes in the Lamb-wave parameters (i.e., wave speed, mode conversion, phase change, and attentuation) as it propagates through the medium and interacts with structural features can be used to identify the thermal characteristics of the system.

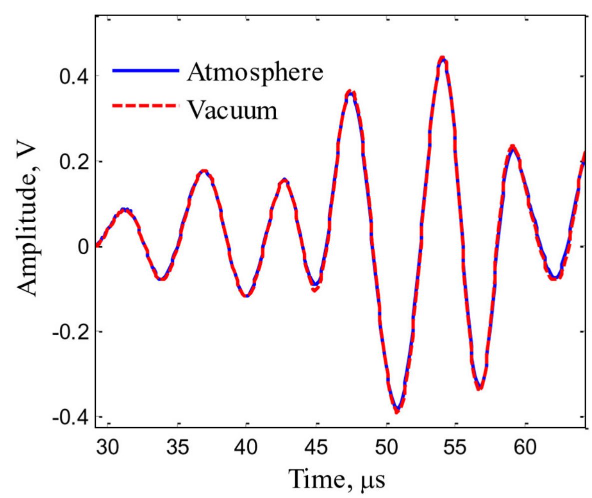


***Figure 1.*** *A Lamb wave measured across an aluminum plate under atmospheric and vacuum conditions.*

To demonstrate the technique, we tested a simple lap-jointed cantilever beam inside a vacuum chamber. The apparatus was first tested in atmospheric and vacuum conditions to confirm both waveform consistency (see Figure 1) and sensor bond integrity, and also to prove that wave propagation is analogous to conductive energy transfer. Subsequently, a thermal gradient (10°C to 80°C) was applied across the specimen under vacuum conditions. Temperature and SHM measurements were made across the lap-joint at bolt torque measurements of 0, 10, 30, and 50in-lbs, or 0, 1.13, 3.39, and 5.65Nm (see Figure 2). The results show that phase, amplitude, and overall signal shape

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vary with transmitted energy, and are correlated to thermal resistance. The waveforms measured at different torques are in reasonable agreement, though there is an increase in acoustic resistance above 30in-lbs (3.39Nm).

Ultrasonic measurements demonstrate conductive energy transfer due to significant impedance mismatch, whether or not an atmosphere is present. Waves that travel through an interface will experience several phenomena that are difficult to clearly illustrate on a single sample: there are wave speed changes as a result of applied strain,[3] wave energy attenuation caused by mating interfaces, and a series of overlapping mode conversions that alter waveform shape at every interface.[2] Developing the proper analytical representation of these features is the current challenge. Our early results show reasonable correlation with thermal methods but, since there is no thermal analogy for mechanical damping, this feature must be properly isolated and removed from the equation to eliminate the trend discrepancy shown in Figure 2.

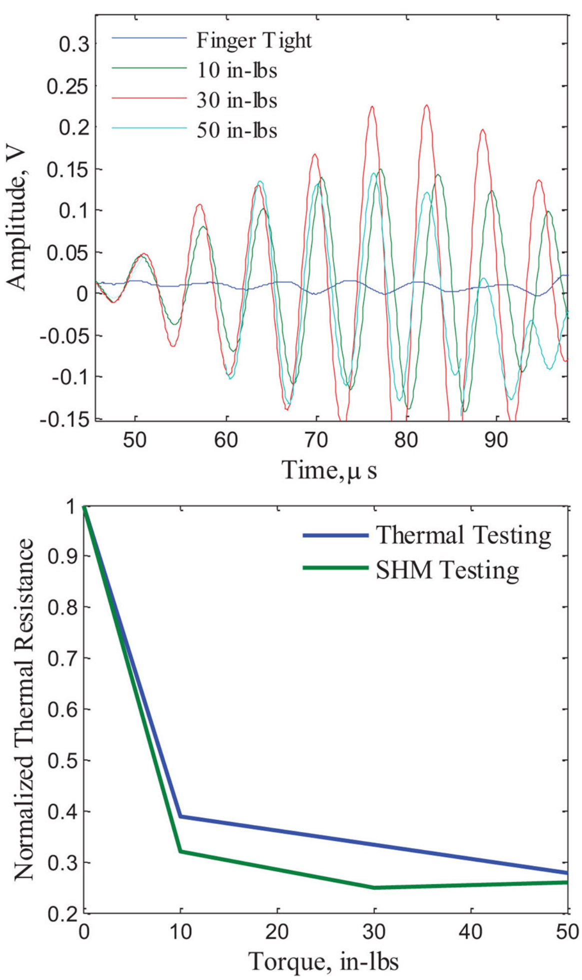


***Figure 2.*** *SHM waveforms measured across a bolted interface at increased torques (top) and normalized thermal resistance of thermal and SHM tests (bottom).*

Current satellite AI&T processes are configured to mitigate the risk of failures due to inadequate interface contacts that impede heat flow and inhibit the cooling of electronic components. A nondestructive method that can perform the same function on-demand without the use of a TVac chamber would be beneficial. We are developing an algorithm that relates ultrasonic to thermal energy transmission. This will allow technicians to evaluate systems in real-time and will provide significant improvements to costs, schedules, performance, and risk. Development of the algorithms required to quantitatively measure thermal conductance is ongoing.

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